Chapter 46

Development and Performance of Large Diameter Cutters for use on High Performance TBM's

Kenneth Deering, Engineering Mgr. - R&D
Gerald L. Dollinger, Ph.D., Geology Lab Mgr.
David Krauter, Design Engineer - Cutters
Joseph A. Roby, Design Engineer

The Robbins Company, Kent, WA, USA.

Abstract

Three high performance TBM's equipped with large diameter (483mm) disc cutters are currently operating in Norway. This paper summarizes the design philosophy, field performance and ongoing technical development of these cutters. Included are discussions of the early problems encountered with their usage and the solutions to these problems that have been developed. Also included are discussions of the penetration rates and cutter usages observed. From this data it is concluded that high performance TBM's with large diameter cutters can produce significant improvements in both overall performance and in cutter costs under hard rock conditions.

Introduction

Improvements in TBM performance under hard rock conditions have been primarily the result of increased thrust and power. On Robbins' TBM's, for example, the average power per foot diameter has increased from approximately 110 kW/m in the early 1960's to over 171 kW/m in the 1980's. During the same period, rated maximum cutter load increased from less than 90 kN to approximately 224 kN and cutter diameters increased from 279 mm to 432 mm to accommodate the additional load. Increases in TBM thrust and power have resulted in better performance in hard rock by allowing increases in both cutter penetration and cutterhead RPM.

The most recent development in hard rock TBM technology has been the introduction of high performance TBM's utilizing 483 mm cutters. Three of these machines are currently boring 3.5, 4.3 and 5.0 meter diameter tunnels at the Svartisen Project in Northern Norway. TBM 1410-251 is designed to be expanded from 4.3 meter to 5.0 meter diameter. TBM 1410-252 is a 4.3 meter diameter and TBM 1215-257 is a 3.5 meter diameter. The 4.3/5.0 meter machines are equipped with 2350 kW of main drive power and the cutterheads rotate with peripheral velocities greater than 168 m/min. The 483 mm cutters have operating bearing capacities of 312 kN. To date these machines have bored over 15000 m of tunnels in a variety of different rock types including micaschist, mica gneiss, marble, granite, and quartzite, and have set a number of Norwegian performance records including:

Best Shift	55.4 meters
Best Day	90.2 meters
Best Week	360.5 meters
Best Month	1143.0 meters

The purpose of the present paper is to discuss the design philosophy and the performance to date of the 483 mm cutters used on the high performance TBMs. Included will be discussions of the early problems encountered and of the solutions to some of these problems.

CUTTER DESIGN PHILOSOPHY

Both linear cutter test data and TBM field performance data clearly show that TBM performance under all rock conditions is greatly improved by increasing the cutter load. The data also indicates that with increased loads and the resulting increase in penetration, cutters can be spaced further apart to produce more efficient boring and reduced torque requirements. Over the past three decades, improving machine performance with higher cutter loads has been the principal driving force behind the development of larger diameter cutters and more powerful machines.

Along with improving machine performance, large diameter cutters also result in improved cutter ring life (i.e. greater rolling distance) and in fewer cutter changes per meter bored. This, along with the improvement in TBM advance rate, has resulted in making mechanical excavation of tunnels competitive for all but the hardest rock conditions.

In 1985, The Robbins Co. decided to take cutter performance to a new level by developing a 483 mm cutter with a bearing load capacity of 312 kN. This cutter was to be used principally under hard to very hard rock conditions where the improvements in performance and cutter life would have a maximum effect. The design objectives of the new 483 mm cutters were:

1. Increase bearing size so that bearing roller stress would remain comparable to that of 432 mm cutters operating at 222 kN.

2. Improve chipping resistance of the disc cutter ring.

3. Eliminate vulnerable fasteners such as end retainer bolts.

4. Eliminate housing seat destruction from high impact loads.

5. Improve seal reliability.

To meet these objectives a substantially different cutter configuration was developed. Most notable is the direct contact of the shaft with a hardened housing seat and use of a wedge block and single bolt for mounting. Also of significance is the use of a threaded locking nut in place of retainer bolts. The shaft is surface treated to prevent galling and freezing of the lock nut.

DESIGN EVOLUTION

Efforts to improve cutter performance at the Svartisen Project have been continual. Included among these have been modifications to the cutter tip profile, changes in the cutterhead profile, improved cutter ring materials, and the implementation of a new cutter maintenance schedule. These changes have resulted in greatly reducing the rate of ring wear and the number of blocked cutters (catastrophic bearing failure) experienced. In addition, some changes were made in the methods of handling the large diameter cutters resulting in reduced cutter change times and higher machine utilization. All of these changes will be discussed in greater detail in the following sections.

Cutter Tip Profile

To date, only cutter rings with a constant cross section have been used on the high performance TBMs. The -251 and -252 TBMs began boring with a dress of 14.3 mm tip width cutter rings in all face positions. This tip width was chosen to maximize the penetration of the cutters while still providing sufficient strength to maintain the integrity of the rings at the expected cutter loads. These rings were observed to work well under most ground conditions and the first 3400 m of the -251 tunnel was bored with them. However, in the hardest rocks, requiring cutter loads greater than 28 tonnes, the rings were observed to chip at the edges.

It was suspected that one reason for the chipping was high stress on the cutter edges, due to high loading and a small contact area with the rock. To reduce edge stress, rings with a wider tip width (19 mm) were tried. This change proved to be very successful and the frequency of chipping above 28 tonnes has been greatly reduced on all machines.

Cutter Metallurgy

Initially the 483 mm disc rings were made from bearing quality steel and hardened in agitated oil. Now a premium bearing quality steel conforming to vacuum arc remelt standards is employed. The composition is no longer an AISI standard but is a Robbins proprietary chemistry. The hardening process has been progressively refined to give higher hardness without loss in fracture toughness. All of these changes have resulted in enhanced resistance of the cutter ring to chipping and spalling.

With the present 19 mm tip width and enhanced metallurgy, the 483 mm disc has been demonstrated to be fully capable of achieving an acceptable life (m^3/ring) without excessive chipping at 312 kN loading. In addition, the measured penetration is significantly better than observed for 432 mm cutters under similar ground conditions using the same tip width and loaded to 222 kN.

Cutter Head Profile

Figure 1 shows the percent of cutters changed at each position on the 4.3 m cutter head of 1410-252 machine. The data clearly shows that cutter life decreases in the outer face (transition) positions of the cutterhead.

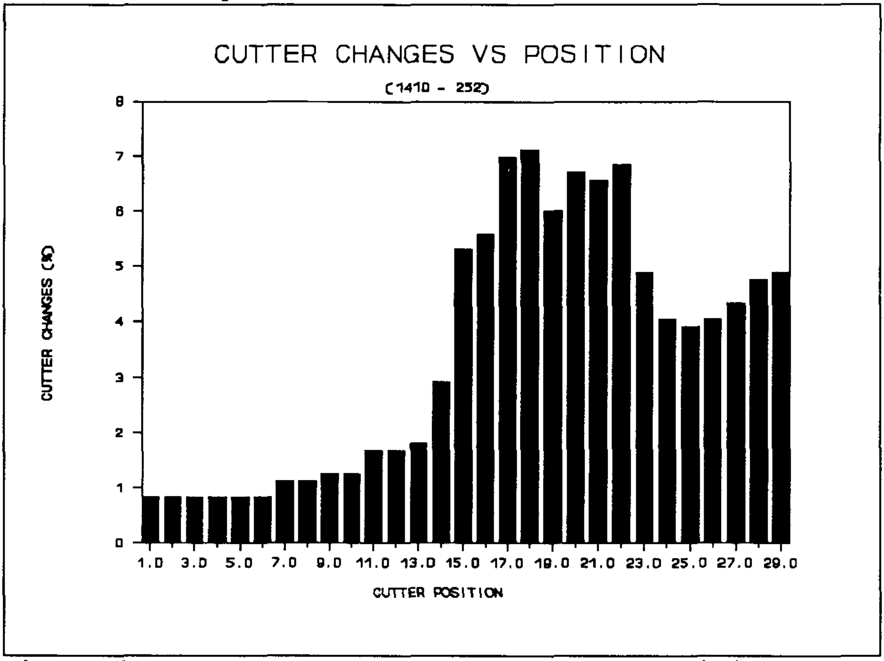

Figure 1 Percent Cutters Changed vs. Positions (TBM 1410-251).

The reduction in cutter life in the transition region is due to an increase in both the rate of cutter ring wear and in the number of blocked cutters that occur in the region. The second observation is well illustrated in Figure 2, which shows the percent of blocked cutters by position on the cutterhead. The increase in ring wear and blocked cutters in the transition region implied that the cutter loads are higher in this region than in other areas of the cutterhead.

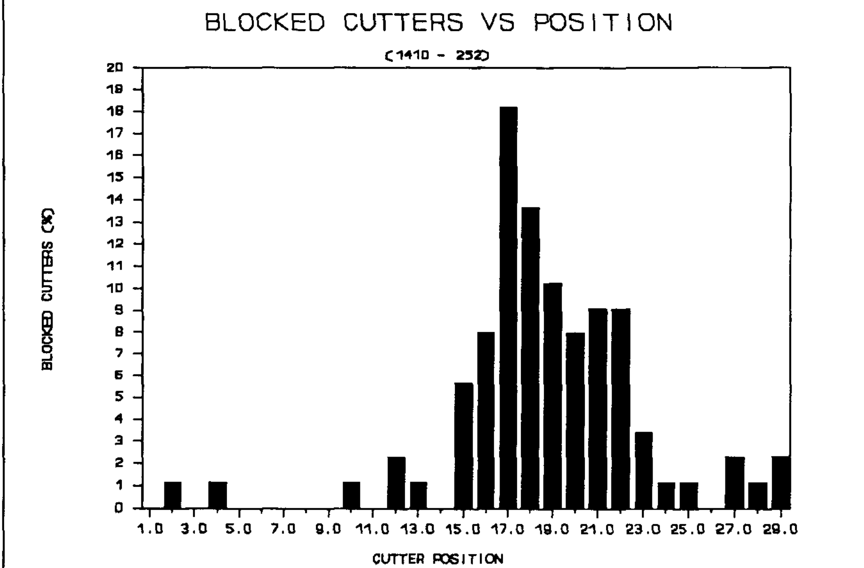

Figure 2 Percent Blocked Cutters vs. Position (TBM 1410-252).

To confirm the evidence of high cutter loads, measurements of individual cutter loads were made. A data acquisition system which included a number of instrumented cutters (strain gages mounted in the shafts) and a slip-ring to transfer the signals from the cuttterhead was installed on TBM 1410-252. In October of 1989, cutter load data was collected from several cutter positions during normal TBM operation. The measurements revealed that the cutter loads in the transition positions were, in fact, over 28% higher than in other regions of the cutterhead.

Linear cutting tests conducted at the Colorado School of Mines (Ozdemir, 1977) have demonstrated that cutter load is a function of the spacing between cuts and increases as spacing increases. Thus, reducing cutter spacing in the transition positions would be one way in which the cutter loads and wear rates could be reduced in those positions.

To reduce the cutter spacing in the transition positions of TBM 1410-252, two additional cutters have been added to the cutterhead during its conversion to 5.0 meter diameter. The addition of these two cutters reduces the cutter spacing in the transition area by approximately 24%, thereby reducing the cutting forces and the rate of wear on the cutters. At the time that this paper is being written the 251 machine has not yet started boring with its new cutterhead configuration.

Maintenance Procedure Changes

A second reason for blocked cutters in the transition positions is believed to have been the job site practice of operating with excessively worn cutters in these positions. This increases the contact area between the cutter and the rock, and increases the cutter loads required to penetrate the rock. The higher load acting on the cutter bearings result in higher internal temperatures and result in increased bearing and seal failures.

When new cutters are installed to replace an excessively worn cutter, the new cutter is initially subjected to very high loads as it reshapes the rock face to the new contour. Although the time for reshaping the face is short, the cutter load is extremely high.

Also, a relatively new cutter operating between two very worn cutters requires the new cutter to remove rock from a concave surface. The surface being further from the new cutter tip requires a crack to propagate further to form a chip. The result is very inefficient cutting.

To increase cutting efficiency and enhance total cutter life in the transition positions, a strict cutter maintenance program was initiated at the Svartisen project. This program involves:

1. Color coding all cutters in the cutter shop to track the number of rings installed on a cutter body (i.e. set of bearings).

2. Setting limits on the maximum wear allowance on a single cutter, and on the maximum wear difference that can occur between adjacent cutters.

The program requires cutters with the newest bearings to be installed in the most highly loaded transition positions. Cutters that have had several ring changes, and therefore have older bearings, are installed in the face positions.

By controlling the maximum wear, inefficient cutting and excessive cutter loads are reduced. And controlling the maximum wear difference between adjacent cutters prevents excessive loading of the unworn cutters.

Cutter Handling System for 483 mm Cutters

To offset the problems of increased cutter weight, a new cutter handling system was developed at the job site. This was done in conjunction with the cutter change crews. Because the people who must use the new system played an active role in its design, a significantly improved cutter handling system has evolved. The system allows easy transport of the cutters from the backup to the tunnel face by using a cable winch, a cutter sled and a portable cutter track. This has enabled crews to achieve an average change time of 30 minutes per cutter.

FIELD PERFORMANCE

Field performance has shown that most of the original design objectives for the 483 mm cutter have been met. Cutter rebuild rates (number of cutter rings used before new bearings are required) are the same or better than the rebuild rates for 432 mm cutters operating in similar rock. Hub and shaft failures have been virtually eliminated.

The hardened cutter-housing seat, with direct shaft to housing mounting, has resulted in a very durable cutter-housing. To date there have been no cutter housings replaced and it appears that no replacements will be required. The two bolt, wedge-lock cutter retaining system has proven to be more reliable than systems used in the past.
The previously discussed design changes have yielded steadily increasing cutter performance as measured in both cutter life and cost.

Although cost for the 483 mm cutter components is higher than 432 mm components, increased component life and cutter penetration rate for the 483 mm cutter has resulted in comparable cutter costs per cubic meter and fewer cutter changes per cubic meter.

SUMMARY AND CONCLUSIONS

Experience with the high performance TBMs in Norway to date indicates that the 483 mm cutters are capable of sustaining a significant increase in penetration when compared to 432 mm cutters in similar rock. Success in eliminating problems with end retainer bolt failures, housing seat destruction and housing bolt failures has been noteworthy. The bearing load capacity has proven adequate at the rated cutter load and techniques to increase this capacity are being explored.

Additional improvements in cutter disc chipping resistance, however, have proven to be considerably more difficult than expected. It is important to note that, with the 483 mm disc rings, the absolute limits of the technology of ultra high strength steel have been reached. Because of this, the increments of improvement come slow and hard, requiring large investments in both time and money. The long term objective for the cutter rings is to advance the cutter steel technology to a point where a narrower tip width can be used on the 483 mm cutter at 312 kN loading.

At this time, field data has demonstrated that 483 mm cutters, loaded to 312 kN, are capable of achieving at least 25% higher penetration rates than 432 mm cutters, loaded to 222 kN, under comparable ground conditions. Cutter costs per cubic meter for the 483 mm cutter have been comparable to those for the 432 mm cutter in similar ground.

In harder rock than at the Svartisen Project the 483 mm cutter is expected to provide yet better performance, when compared to other cutters, because of it's greater load capacity and extended component life.

REFERENCES

Ozdemir, L., et al., 1977, "Mechanical Tunnel Boring-Prediction and Machine Design, "Annual Report to National Science Foundation", Contract No. APR-73-007776-A03, Colorado School of Mines.